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Detailed Three-dimensional Anatomic Characterization of the Human and Canine Thyroarytenoid and Cricothyroid Muscles

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Abstract

Detailed muscle information has become increasingly valuable as biomechanical models of the larynx have grown in complexity. For example, it has become progressively important to have more details of laryngeal muscle size, direction, muscle structure, and muscle shape (e.g., shape of muscle at origin and insertion), as well as inter-muscle spatial relations. Presented in this report are data of four male and four female canine larynges. Specifically described are details of the intrinsic abductor and adductor musculature of the canine larynx: the posterior cricoarytenoid, the lateral cricoarytenoid and the interarytenoid muscles. Also presented are the three-dimensional representations of four to five muscle bundles of each muscle. Through the use of this resource, it is expected that biomechanical models of laryngeal mechanisms can take a needed step into realism in order to support and explore clinical phonosurgical therapies. Quantification of vocal fold geometry is necessary for the development of anatomically realistic and consistently defined experimental/computational models of the glottic and subglottic regions. Such models will facilitate the study of the influence of the subglottis in voice production.

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1. Introduction

Laryngeal muscles, with the surrounding cartilages and joints (Kim, Hunter, & Titze, 2004; Selbie, Zhang, Levine, & Ludlow, 1998), posture the vocal folds via length change and abduction/adduction (Farley, 1996). Thus, as a primary mechanism behind posturing, laryngeal muscles are key to overall health (ventilation, swallowing, and effort closure of the airway (Kraus et al., 1996)) and voice (vocal onset, self-sustained oscillation, intensity, and pitch (Cooke, Ludlow, Hallett, & Scott Selbie, 1997; Hirano, Vennard, & Ohala, 1970; Honda, 1983; Murry, Xu, & Woodson, 1998; Titze, 1988; Titze & Sundberg, 1992)).

Knowledge of laryngeal structure (e.g., cartilages and soft tissue) and musculature (e.g., intrinsic laryngeal muscles' orientation, strength, and type) is needed to understand the mechanisms of posturing and phonation. Previous studies of laryngeal muscles have largely been whole muscle descriptors, focusing on quantifying average size (i.e., length and cross-sectional area), overall orientation, and mechanical characteristics (e.g., stress-strain relations and contraction times). For example, Cox et al. (Cox, Alipour, & Titze, 1999) described the size, length and direction of human and canine cricothyroid (CT) and thryoarytenoid (TA). Finally, whole muscle mechanical characteristics have been reported for many of the laryngeal muscles (Alipour & Titze, 1999; Alipour, Titze, Hunter, & Tayama, 2005; Alipour et al., 2005; Alipour-Haghighi & Titze, 1985, 1991; Alipour-Haghighi, Titze, & Perlman, 1989; Alipour-Haghighi, Perlman, & Titze, 1991; Alipour-Haghighi, Titze, & Durham, 1987; Cooper, Partridge, & Alipour-Haghighi, 1993; Cooper, Pinczower, & Rice, 1993; Cooper, Shindo, Sinha, Hast, & Rice, 1994; Hunter, Alipour, & Titze, 2007; Perlman, Titze, & Cooper, 1984).

Although studies like these have provided a valuable foundation for understanding laryngeal muscles, a disconnect often exists between the findings of previous whole muscle studies (which use averages as a complete picture of a particular muscle or group of muscles) and the intricacies of a muscle with non-uniform structure (Titze & Hunter, 2004), shape (Tayama, Chan, Kaga, & Titze, 2001), function (Hunter, Titze, & Alipour, 2004) and mechanics (Alipour et al., 2005; Hunter & Titze, 2007), as well as the entire laryngeal system with inter-muscle mechanical dependencies and relationships. For example, whole muscle studies cannot be used to explain why portions of individual laryngeal muscles have specific posturing functions (Brandon et al., 2003a, 2003b; Han, Wang, Fischman, Biller, & Sanders, 1999; Sanders, Han, Rai, & Biller, 1998; Sanders, Han, Wang, & Biller, 1998; Sanders, Rao, & Biller, 1994). Neither can they be used to explain how to compensate for some medical pathologies or post-operative conditions, which leave only portions of an individual muscle viable for laryngeal control (Peretti et al., 2000; Zealear, Billante, Courey, Sant anna, & Netterville, 2002). Further, previous whole muscle studies have not addressed inter-muscle spatial relations, which must be known to adequately understand and model such conditions as laryngeal asymmetry, a common symptom of numerous laryngeal pathologies.

Thus, specific laryngeal information is particularly important for laryngeal models (of both phonation and posturing), the goal of which is often to lay the foundation to predict vocal injury (Hunter et al., 2004; Titze & Hunter, 2007). If refinements were made to the basic assumptions and the anatomical information on which these models are based, the results of small variations in glottal therapy and phonosurgical interventions such as vocal fold medialization could be accurately and non-invasively simulated. Thus, detailed distributed muscle information, which would enhance the understanding of vocal fold mechanics, is essential.

The goal of this manuscript is to present fibre bundle orientations of human and canine CT (in particular, the pars recta, CTR, and the pars oblique, CTO) and TA. Specifically given are laryngeal muscle bundle origin and insertion points in three dimensions with corresponding average muscle area, approximated with simple cross-sections

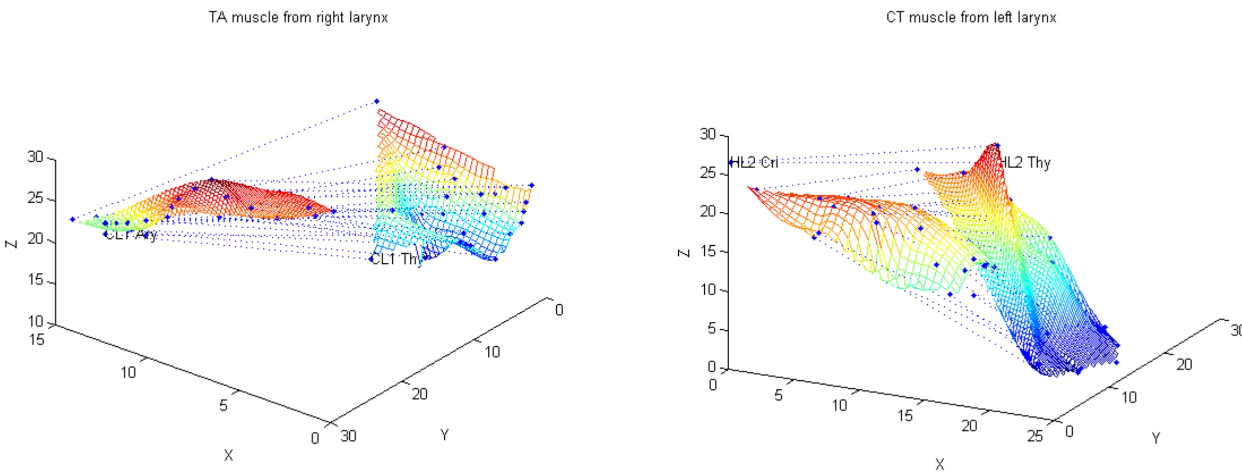
2. Data

No new data muscle data were collected for the current report. Rather, existing data from both the CT and TA muscles from six human males and three canines were taken from raw data (Cox, 1996). For this study, the larynges were prepared so that the major cartilages and intrinsic muscles remained in the framework. The cricothyroid muscle was exposed (specifically, the CTR and CTO). The TA muscle was exposed by removing the vocal fold mucosa and vocal ligament so that all of the TA muscle fibers were visible. A pin was inserted through both the CT and the TA joints to establish origin points and to keep the joints from moving. A three-dimensional mechanical positioning system with the vernier markings was used to measure ends of the muscle bundles with an accuracy of 0.1mm. For each specimen, the left CT and right TA were dissected. The three-dimensional origin and insertion positions were recorded for each bundle. As a bundle was removed, it was weighed using an electronic balance with 0.1mg accuracy. From this bundle weight and the length from the origin and insertion points, cross-sectional area was calculated. Cox *et al.* (Cox et al., 1999) published the length of the TA (averaged from the bundles), as well as the area and the angle (direction) in the coordinate system defined in the paper. Also published were the averaged area, angle, and length of the total CT and its two portions, the CTR and CTO.

The raw data was recovered and converted into electronic spreadsheet tables (available with this Technical Memo) for easy access. The main spreadsheet is ‘CoxThesisTables-Final.xls’. This spreadsheet contains all of the tables of data (Cox, 1996). The first tab (AppA) contains CT and TA three dimensional origin and insertion points for multiple muscle bundles for each of the human and canine specimen. The CTR and CTO are labeled. The second tab (AppB) lists the mass of each muscle bundle mass. The third tab (App C) has the length of each muscle bundle, which can also be calculated from AppA. Tab 4 (App D) is the calculated area of each bundle, assuming the density of muscle tissue of 0.001043 g/mm3. The last tab is an equation based sheet which can recalculate the areas for any given density.

3. Using the Data

In addition to the tables, three other spreadsheets are provided along with a Matlab script. Two of the spreadsheets contain the same information as the first two tabs of the larger spreadsheet presented previously (CoxThisisTables_appA.xls, CoxThisisTables_appB.xls), while the third spreadsheet (CoxMuscleInfo.xls) contains information about where the data exists in the first two tabs. For example, row three contains the information for the first human larynx, with subsequent columns containing numbers used by the Matlab script to find appropriate data about this larynx. Row four contains the data for the second larynx, and so on. Row nine contains the data from the first canine larynx with the third canine larynx data in row eleven. The Matlab script (CoxData.m) loads the data and plots them in two figures, one presenting the TA muscle and the other presenting the CT muscle.



(a) (b)

Figure 1. 3-D rendering of the origin and insertion points of the muscle bundles.

4. Accompanying Files

The files mentioned above were packaged in a compressed zip file called NLDR_0000005_v10.zip, which contains the following files

File	Description
CoxThesisTables-Final.xls	Full Data of muscle bundles
CoxData.m	Matlab script to create plots of muscle data
CoxMuscleInfo.xls	Used by CoxData.m to load various muscle data from the following two spreadsheets
CoxThisisTables_appA.xls	Subset of full data used by Matlab script
CoxThisisTables_appB.xls	Subset of full data used by Matlab script

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Revisions

1.0 Eric Hunter: Main document (March 2012)
  1.1 Eric Hunter: Minor wording fixes (April 2012)
2.0 Laura Hunter: imported into new template, technical writing review (April 2015)